Multifunctional Composite Direct Methanol Fuel Cell

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Outline

- Multifunctional composite materials
  - Background & general motivation
- Multifunctional composite DMFC
  - Approach
  - Design
  - Performance
- Conclusions
  - Future research

Background

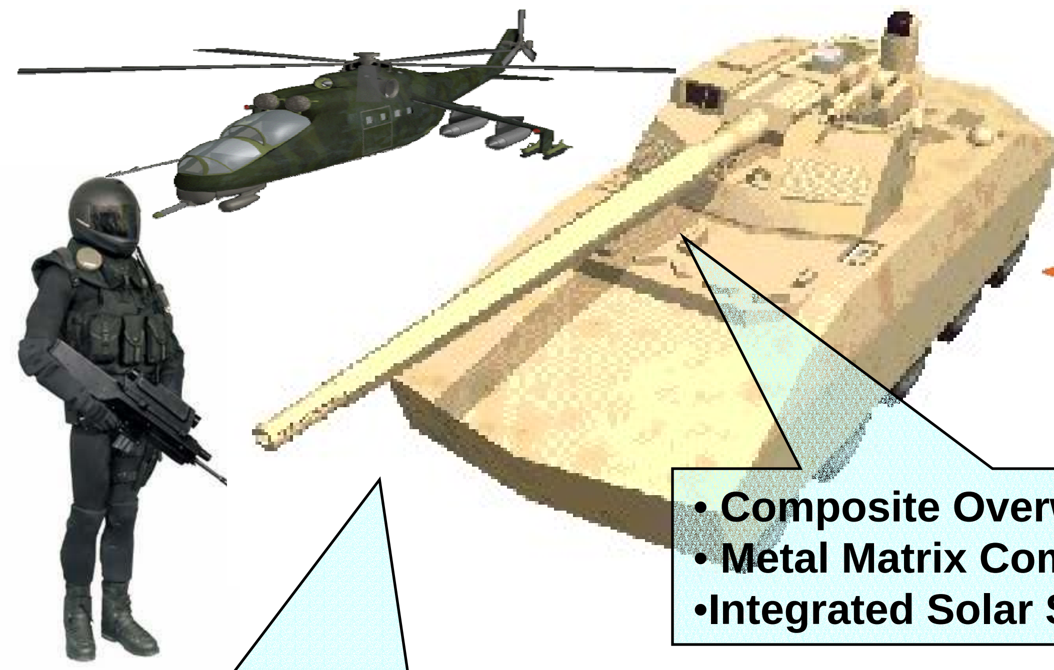
- Army systems increasingly demand more efficient use of material mass and volume
  - Examples
    - 80-ton M1A2 tank to be replaced by 20-ton vehicle
    - Future soldier systems will require increasing power and electronics demands, higher level of armoring
    - Munitions getting “smarter”: must contain explosives, processors, sensors, guidance, actuators, power supply
  - Simple “additive” designs are not capable of meeting the design requirements
- Multifunctional composite material / structure
  - Inherently provides more than one functionality:

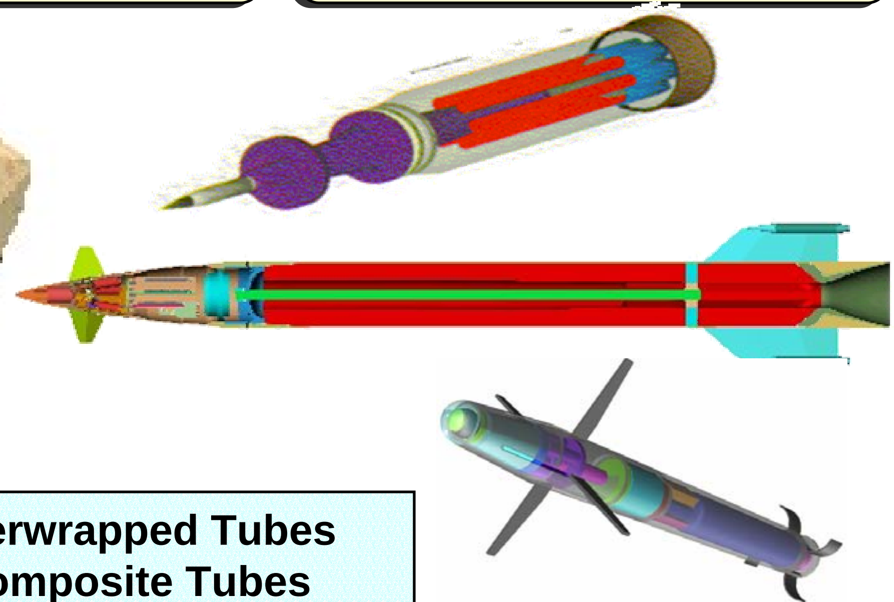
structure | ballistic protection | chem-bio protection | health monitoring | sensing | power generation | actuation | communication | electromagnetic properties

  - A successful multifunctional composite MUST improve performance, reduce complexity, or reduce costs relative to conventional designs

Army Composites Applications

Integral Structures/Armor	Lightweight Armaments	Advanced Munitions





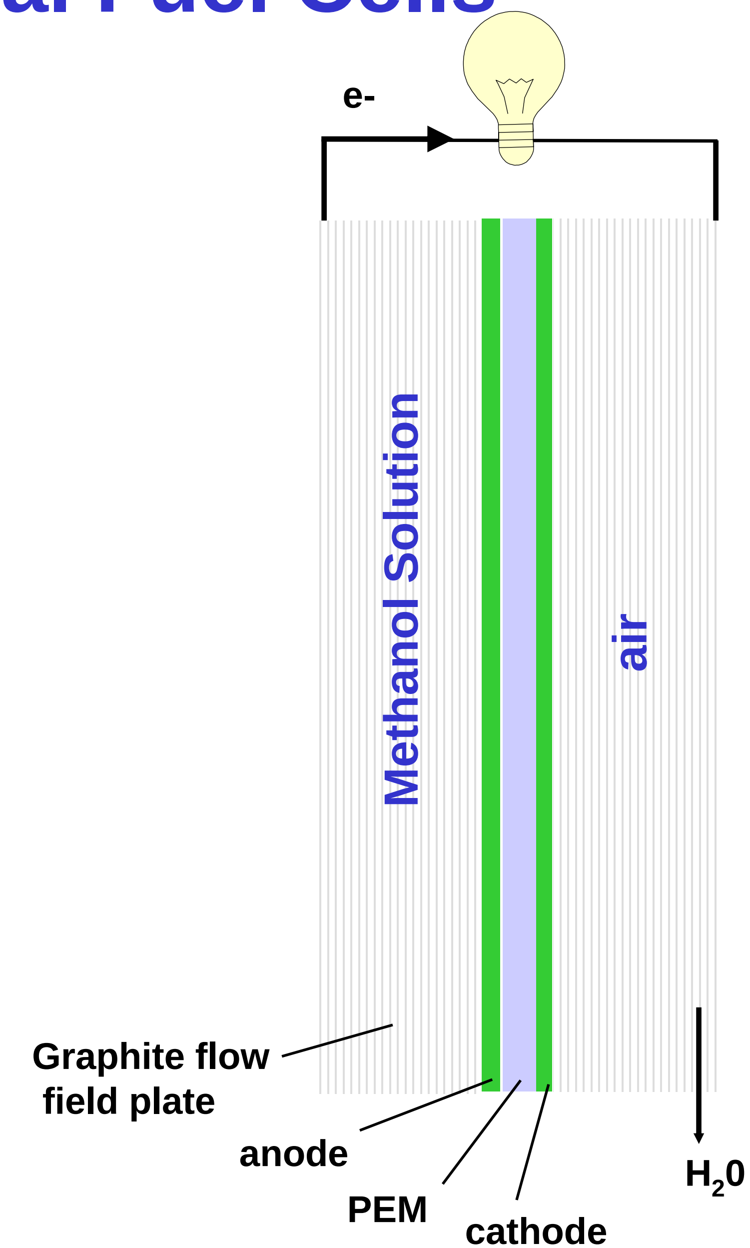
- Composite Overwrapped Tubes
- Metal Matrix Composite Tubes
- Integrated Solar Shroud/Stiffening

- Composite Structural Vehicular Armor
- Low-Cost, Thick-Section Composites
- Personnel Protection
- Rotorcraft Airframes and Crew Armor

- Composite Sabot
- Smart Control Surfaces
- Ejectable Composite Cases
- Thin Composite Shells

Conventional Fuel Cells

- Conventional designs are optimized for power not stiffness
- Power is achieved through stack design
- Stiffness and strength exist to support the stack and accompanying components



Power-Generating Multifunctional Composite Material

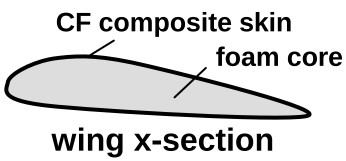
- Goal: Design / fabricate a material / structure which
  - Supports load or provides ballistic protection
  - Stores, converts, or produces power / energy
  - System-level performance gains are achievable even if the individual power and structural performances are inferior to mono-functional designs
    - System-level weight savings result from material mass providing multiple functions
- Potential applications:

Platform	Power needs	Structures / armor
Soldier systems	displays, communications, sensors, warmth	helmet, body armor, backpack rack
Unmanned aerial vehicles (UAVs)	primary power, guidance and control, communications	frame, skin, aero structures
Mules	primary power	primary structure, armor
Smart munitions	guidance, sensors	projectile casing, aero structures
Future combat system (FCS)	primary power, communications, sensors, electromagnetic armor	primary structure, armor

UAV Wing and Fuel Cell

aerodynamic structure and power generation

- Proposed S.O.A.R. U.A.V. construction
  - Wings: carbon fiber composite skin with foam core
  - Capabilities limited by interior volume of fuselage

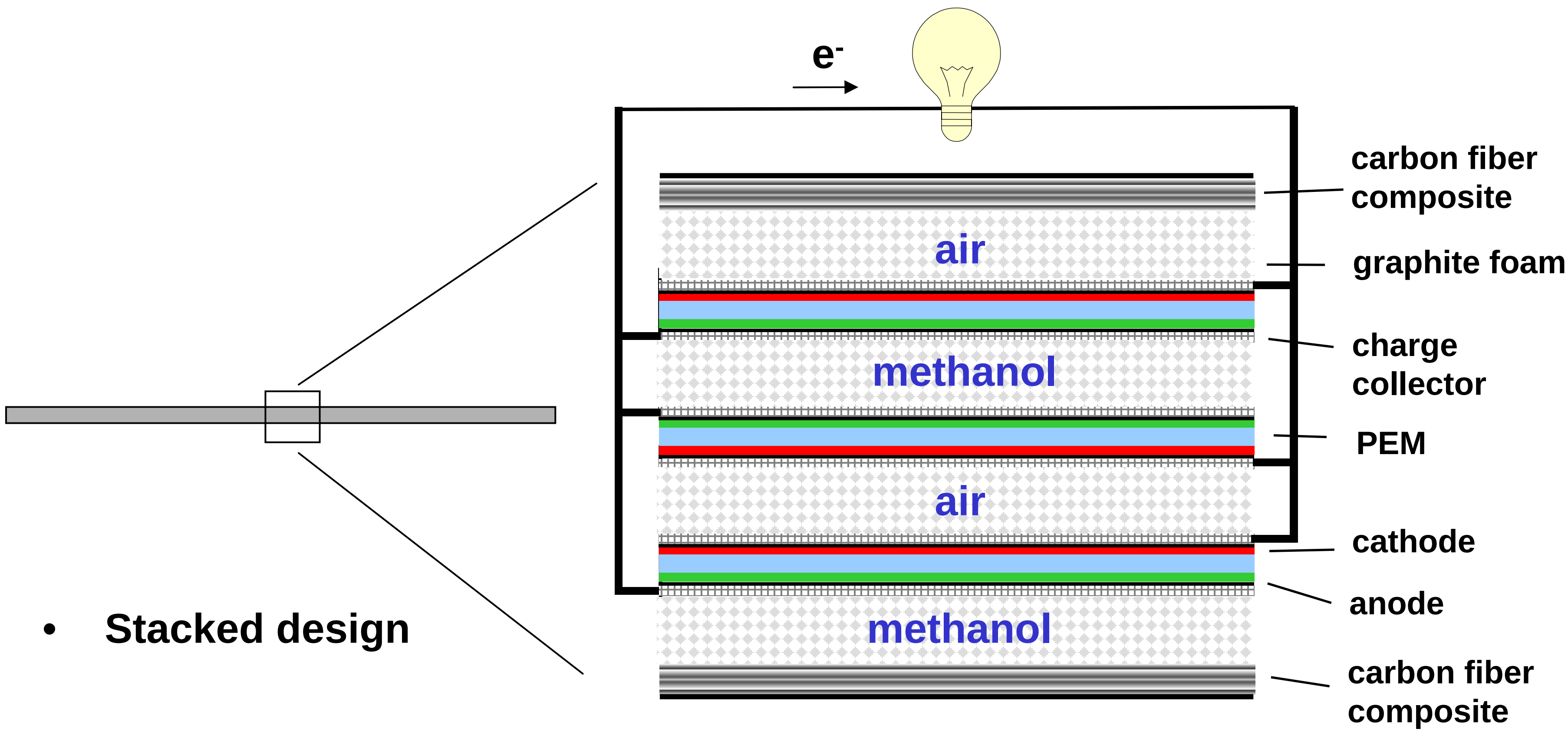


- Power requirements
  - CCD/IR camera, communications, guidance, primary power

- Multifunctional design
  - Use wings as direct methanol fuel cell
  - Carbon fiber skin acts as collector plate
  - Replace foam core with graphite foam core / PEM / anode / cathode
  - User fills the fuel cell with methanol prior to launch → stores and converts methanol
- Advantages over conventional design
  - Eliminates battery from fuselage, frees volume for other capabilities
  - Potential weight savings

Structural Fuel Cell Concept

- Conventional cathode / PEM / anode
- Metallic or Graphitic foam permeable layer / methanol storage as well as the charge collector plates
  - Foam also provides shear strength and compressive strength for skin-core composite design
- Polymer matrix composite providing structural stiffness

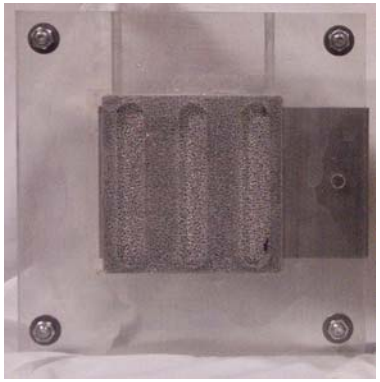


- Stacked design

Structural Fuel Cell Concept

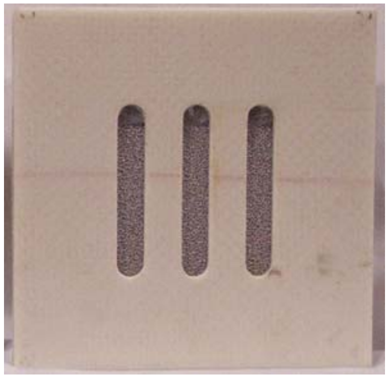
- Three different types of variations on the design have been evaluated
  - Acrylic, Glass/Epoxy Composite, Glass/Epoxy VARTM Composite
    - Compressed Al foam & Carbon foam for the bipolar plates
    - With and without a perforated stainless steel charge collector

Preliminary



- Acrylic
- Mechanically fastened

First generation



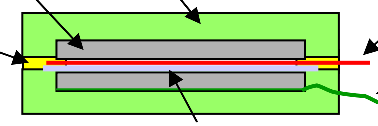
- Glass/Epoxy Composite
- Composite panels manually assembled, adhesively bonded and pressed

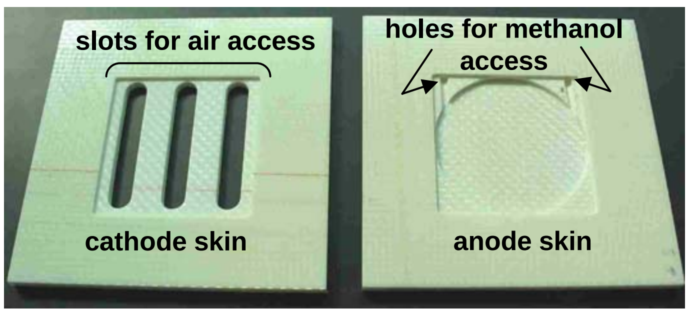
Second generation

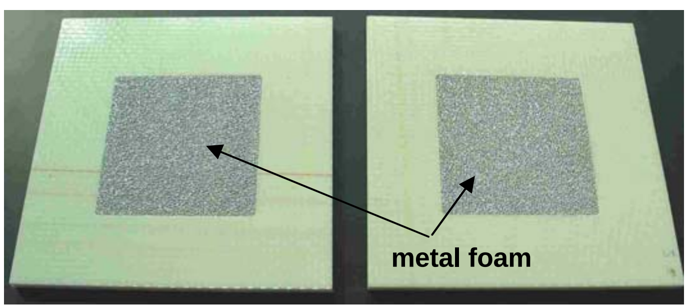
- Glass/Epoxy Composite
- VARTM

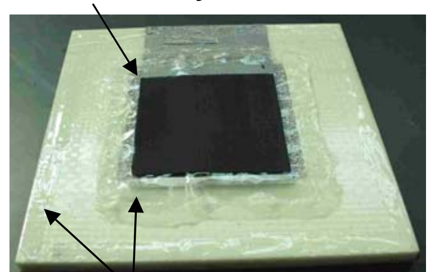
Structural Fuel Cell Prototypes

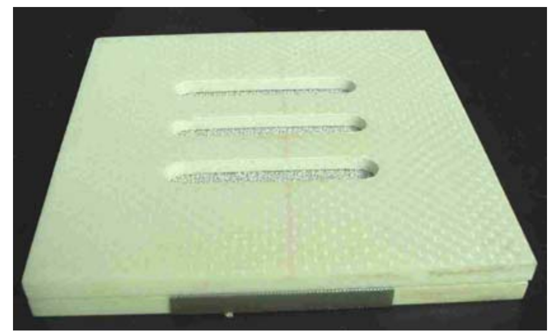
- **First generation: composite skins bonded to fuel cell core**
  - 0.125"-thick open-cell foam core
  - Glass-epoxy skins
    - Skin-core assembly sealed with silicone adhesive then epoxy bonded
  - PEM Nafion 117 with a PT/Ru anode and hot-pressed Pt cathode layer, Active area of 113. 8 cm^2
    - Anode 4.0 mg cm^{-2} Pt/Ru catalyst, cathode 4.0 mg per cm^{-2} Pt catalyst, carbon cloth diffusion layers
  - Surface slots for air circulation
  - Drilled holes for methanol/water access

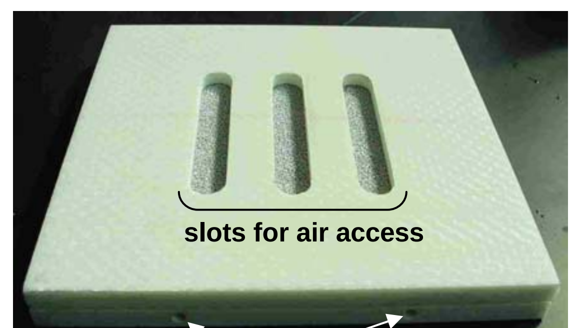




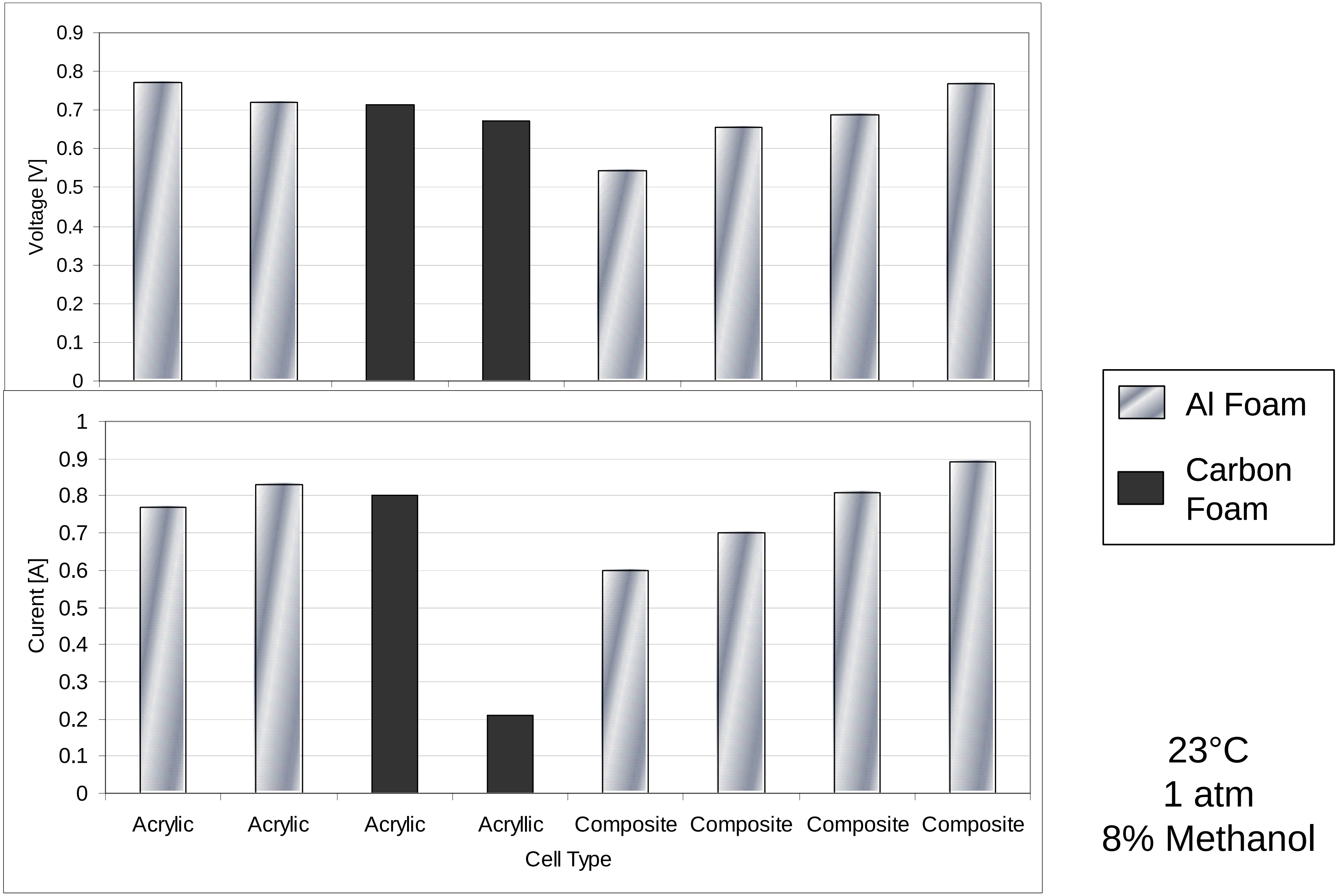






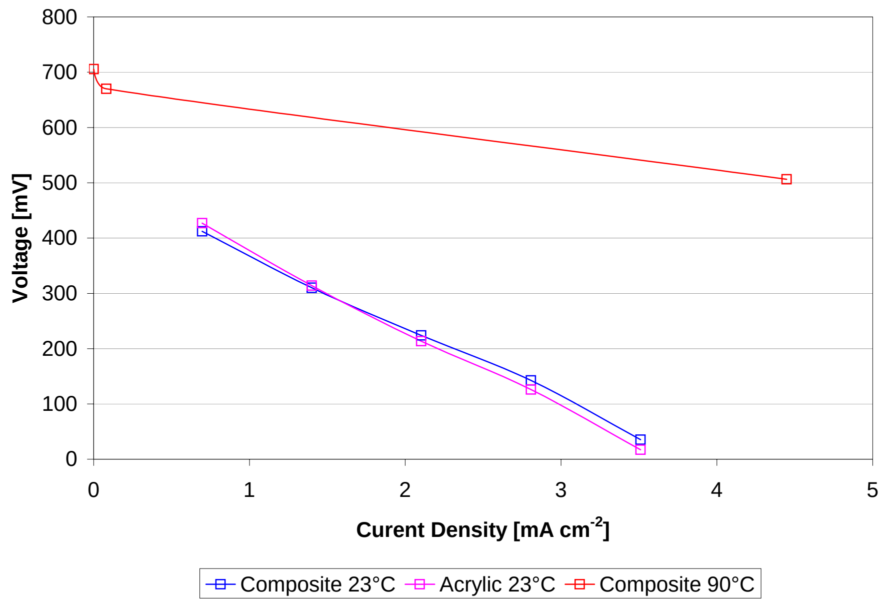


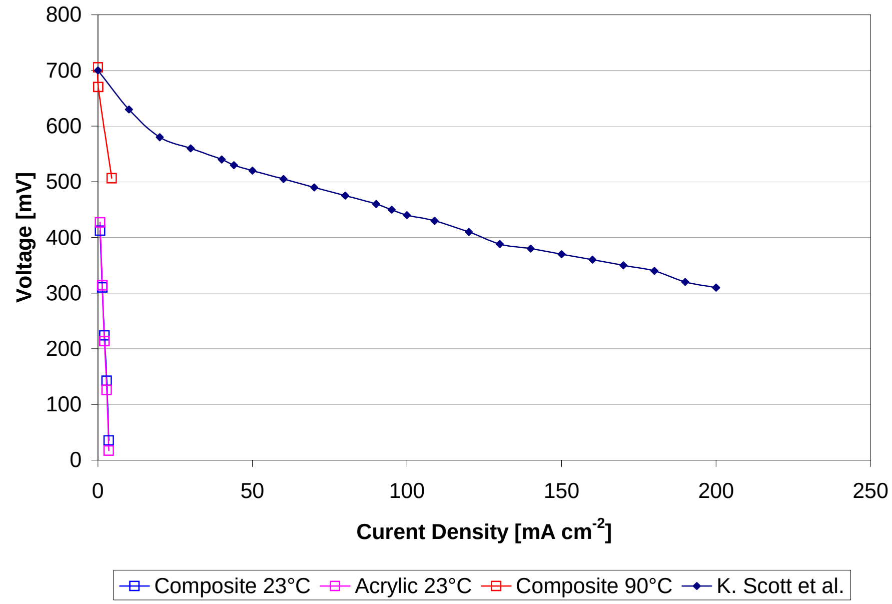
Single Cell Performance



23°C
1 atm
8% Methanol

Single Cell Performance



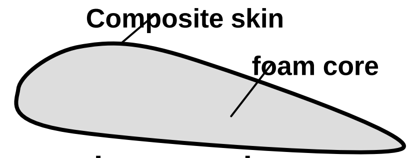


8% Methanol

363 K, 2.0 bar air, 1.36 cm^3 min^{-1}
K. Scott et al., *J Power Sources*, 83 (1999) pp. 204-216

Multifunctional Fuel Cell Structure

- **Second generation: fuel cell within a composite skin.**
  - **Multifunctional wing structure.**



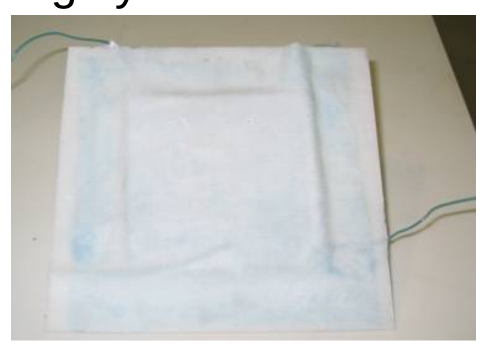
wing x-section

Components are assembled

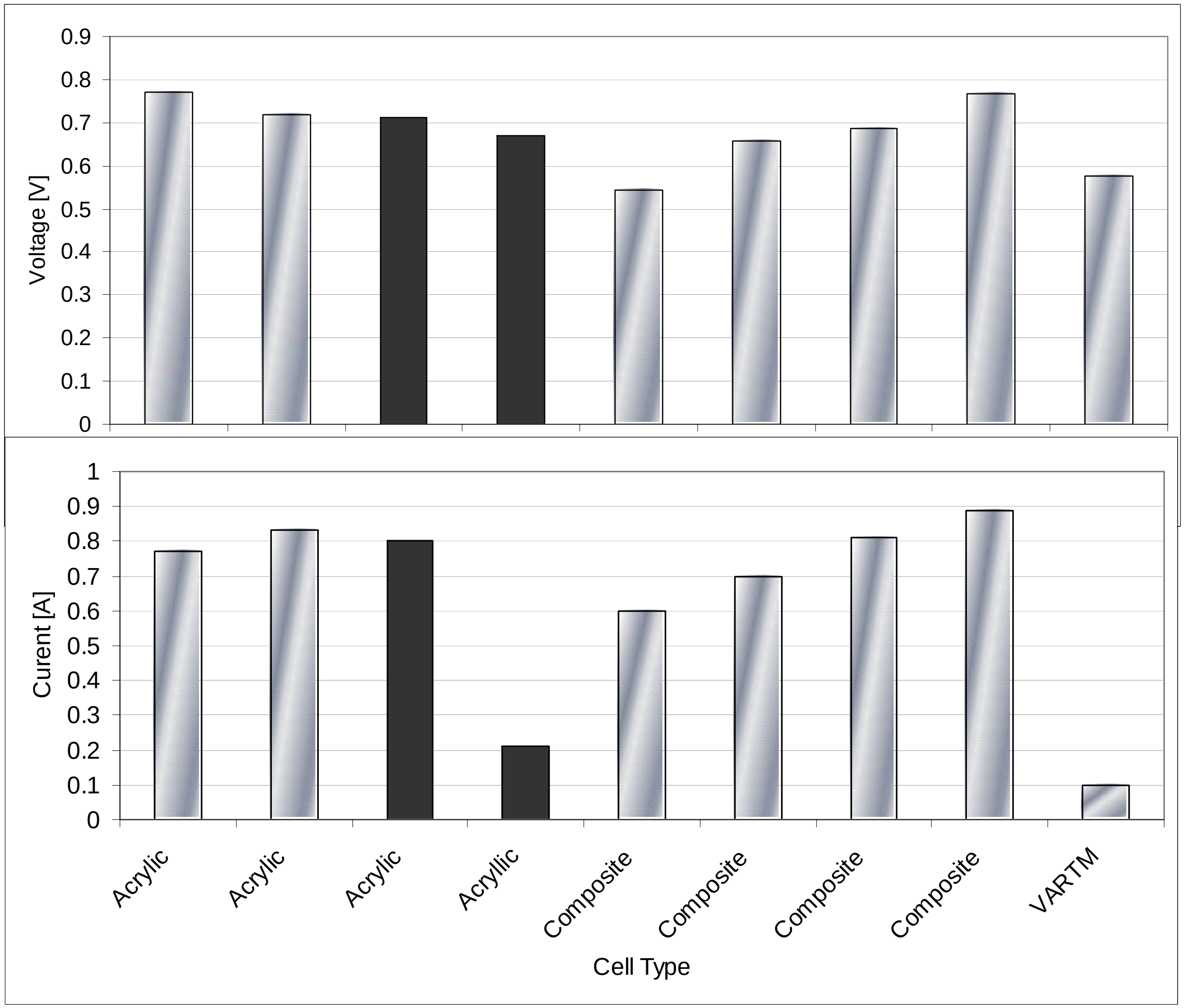
Reactant and electrical connections are added
The components are sealed

VARTM is use to fabricate
The composite

Composite cell is vented and trimmed to size of roughly 22 x 22 cm.



VARTM Cell Performance

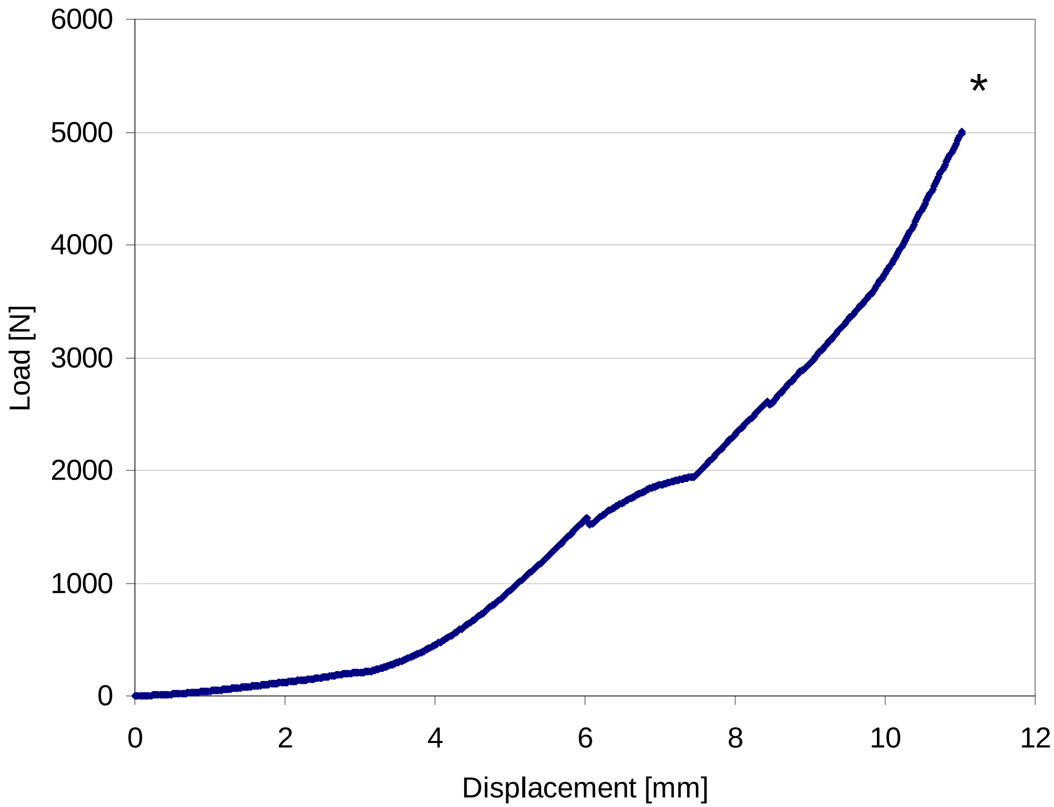


Al Foam

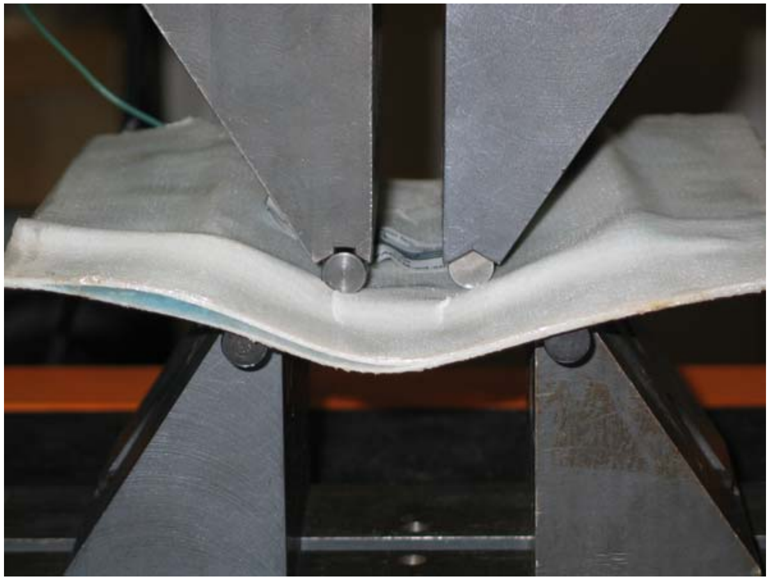
Carbon Foam

23°C
1 atm
8% Methanol

Structural Benefits



- The VARTM fuel cell demonstrated a structural capability
- System failed under four point bend at 5568 N via delamination



Four Point Bend

Conclusions

- A multifunctional DMFC has been fabricated and shown to produce power
- Demonstrated the ability to produce a multifunctional DMFC using traditional composite processing techniques
- The power generation performance of the cells is poor
  - Power performance increases with increasing temperature and pressure
- Limiting kinetics to the reaction
- Next generation design improvements
  - Increase power density by incorporating multiple cells into single stack, reducing individual cell thickness
  - Enhance structural performance by improving core-skin bonding, increasing core-PEM shear strength